91602
new 82-10

ontario hydro
research division

COMPLIMENTARY COPY
Please Credit Ontario Hydro Research if
Reproduced in Whole or in Part

To: Mr J.H. Midgley
Design & Development Division - Transmission
Transmission Stations Design

A FAULT CURRENT DIVERTER (FCD) FOR INDOOR METALCLAD SWITCHGEAR

R. Filter and T. Jarv

Laboratory tests were carried out in the summer of 1987 to assess the potential of the Ontario Hydro developed fault current diverter in providing arcing fault protection for indoor metalclad in Transmission Station buildings. These tests demonstrated that if suitable firing protocols are developed, fault diversion techniques can provide a high degree of protection against smoke and soot damages caused by arcing faults. It is recommended that R & D into a fault current diverter for indoor metalclad switchgear, along with suitable diverter firing protocol, be initiated.

1.0 INTRODUCTION

During the early 1980's, Ontario Hydro experienced difficulties in providing adequate and reliable padmounted distribution transformer protection. At that time, all available protection techniques were centred on fusing and, due to the complex nature of the protection problem, could not be relied upon to work properly under all realistic fault scenarios. As a result, a project was co-funded by the CEA and Ontario Hydro to address the transformer protection problem, and to develop an alternative to fusing in this application. The device resulting from that R & D program is the Fault Current Diverter.

In essence, the fault current diverter (FCD) is a stored energy device which senses a fault and, in response to pre-programed firing criteria, propels a specially designed, grounded electrode through insulation to ground out the faulted circuit and immediately collapse any fault arcing. In FCD designs tested at the Research Division, rapid grounding of fault arcs of 12 kA has been demonstrated. Circuit protection

job	file	date	report no.
14-205-433	813.16	February 12, 1988	87-310-K

89-02594/

LEGAL NOTICE

This report was prepared by Ontario Hydro and, while effort has been made to assure the accuracy and applicability of the material contained herein, neither Ontario Hydro nor any person acting on its behalf:

(a) makes any warranty, express or implied with respect to the use of any information, apparatus, method or process disclosed in this report or that such use may not infringe privately owned rights; or

(b) assumes any liabilities with respect to the use of, or for damages resulting from the use of, any information, apparatus, method or process disclosed in this report.

against arcing damage was shown to be feasible within about 2 ms from the point of fault arc initiation. The fault current diverter is a small, effective, and comparatively inexpensive protection alternative offering significant protection system performance improvements.

In the summer of 1987, a prototype distribution system fault current diverter was incorporated into an on-going test program at the Research Division to evaluate methods developed by the Stations Design Department for the control of smoke and soot during transmission station metalclad switchgear arcing faults. The FCD was applied in a mock-up of a typical new design of TS environment, and its performance during several staged arcing faults in metalclad switchgear was assessed to determine the potential of FCD-based fault protection systems to minimize damages caused by switchgear arcing faults.

Results of that testing indicated that a suitably designed FCD-based station protection system offers significant advantages, from the point of view of pressure rise and smoke migration, over presently used breaker or fuse based protection systems. As a result, it is suggested that further work to better tailor FCD technology and application principles to the TS environment be initiated.

2.0 THE FCD IN TRANSMISSION STATIONS

Many transmission stations have transformer breakers and associated switchgear housed in a single large room. With this arrangement, there are four transformer breakers, each feeding seven to eight feeder breaker cells. Recently, a fire at Slater TS and King Edward TS in Ottawa generated significant amounts of soot and smoke, precipitating switchgear cell failures and resulting in a lengthy station outage.

In the fall of 1986 and the spring and summer of 1987, The Stations Design Department tested a double ceiling concept, switchgear sealing, and a new type of ventilation system at the Ontario Hydro Research Division/1/, the purpose of which was to limit fault growth and station outage duration through smoke and soot control, and with that, to enhance personnel safety during and immediately after a fault. The results of that testing demonstrated it was practical to control the by-products of an arcing fault, limit outage durations, and enhance personnel safety through improved building design, switchgear sealing, and ventilation.

In addition to the new design, consideration was given to the FCD for further improving the fault performance of stations. If a fault arc could be limited in duration to a few milliseconds instead of several cycles, then the amount of soot and smoke generated would be decreased, and with that, the adverse consequences of arcing faults inside station metalclad could be reduced. A further incentive to testing fault diversion principles in the TS environment is that it may prove feasible

to develop FCD-based fault protection systems which could be retrofitted to existing TS buildings, and with that, greatly reduce protection enhancement costs.

3.0 FCD OPERATING PRINCIPLES

The fault current diverter is a device which senses the presence of an arcing fault and very rapidly operates to "ground" the faulted circuit and collapse the fault arc. In the FCD devices so far developed and tested at the Research Division, rapid grounding of the faulted circuit has been achieved in two ways. One approach involved the use of a specially designed "module" which could be attached to bushing wells of padmounted transformers and which, when triggered, would propel a grounded, conducting piston and probe into a set of specially designed contacts/2/. A second successful approach to providing ultra-fast circuit grounding has been tested and involves a specially designed cable piercing arrangement which again propels a grounded piston and contact probe through a section of cable insulation to ground the circuit/3/.

Figure 1 presents a circuit drawing showing a representative application of FCD protection for padmounted distribution transformers.

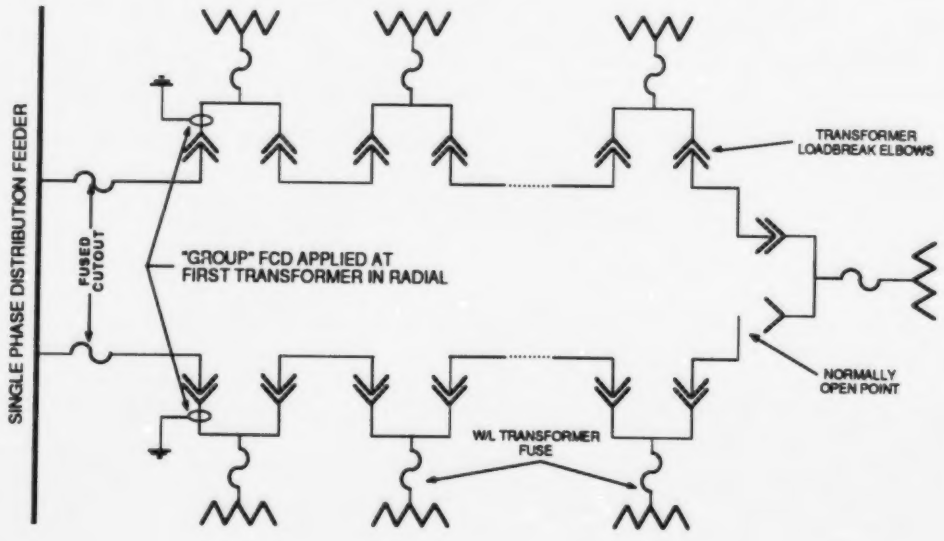


FIGURE 1:
Representative FCD Application for Padmounted Transformers

With both FCD designs, circuit protection against arcing damage was demonstrated to be feasible within about 2 ms after fault arc initiation. In both cases, I^2t let-through values were significantly reduced over values which would have resulted with the best current limiting fuses suitable for the application. Figure 2 presents conceptual cut-away views of both the "module" and the "cable piercing" FCD.

Table I presents the principle advantages and the challenges of applying an FCD based arcing fault protection scheme in the TS environment.

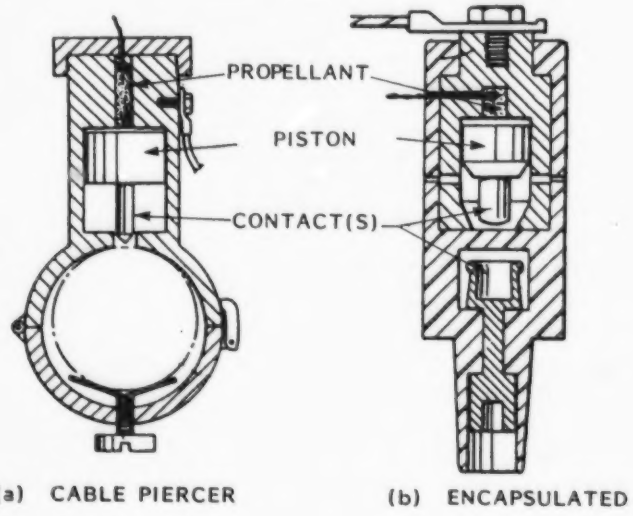


FIGURE 2:
Two Embodiments of the Fault Current Diverter

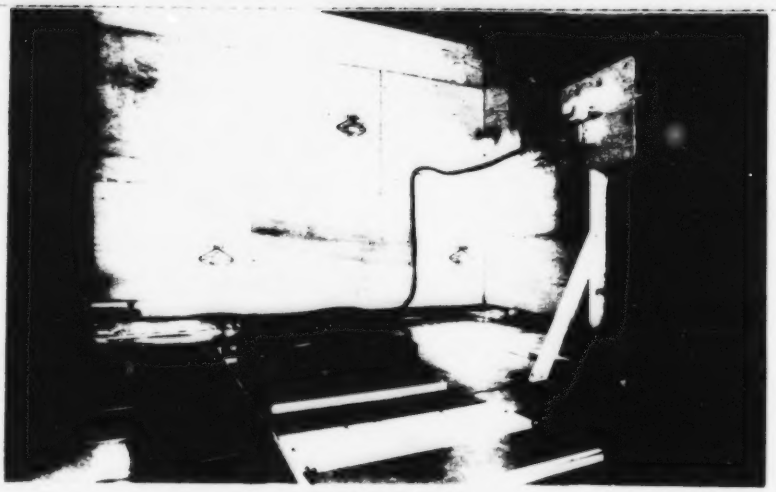
TABLE I:FCD Advantages and Challenges for TS Application

ADVANTAGES	CHALLENGES
-since FCD is a stored energy device, firing can be controlled and tailored to specific applications	-development of a 3 phase FCD which reliably operates with fault current > 25 kA
-more than one fault sensing technique can be used and processed to develop "fail-safe" firing criteria. Some of the criteria which might be used to identify a fault can include: -Current magnitude or rate of rise -Voltage perturbations -smoke detector response -pressure transducer response -light and/or sound -presence of harmonics/spectrum analysis	-development of fault sensing strategy and techniques for Station applications -location of FCD to protect the whole switchgear assembly -modification of system protection to allow bolted three phase fault -reliability assurances for FCD
-immunity from load current	-provision of phase to ground insulation
-reduced fault energy let-through over let-through of fuses or breakers	-development of means for routine inspection and testing of installed FCDs
-ultra-fast arc extinghishing results in virtual elimination of arcing by-products	

4.0 THE TEST SET-UP

The test set-up at the Research Division incorporated a Brown Boveri Corporation (BBC) metalclad cell including, a breaker compartment (with the breaker), a bus compartment (with buswork and bushings), and a cable compartment. The test structure included a false ceiling, front, back and side corridors, along with additional corridors to allow personnel access to the chambers and corridors, and to allow viewing of the tests. The set-up was a scaled down, representative model of a new design of transmission station incorporating the improved ventilation system for smoke removal.

Photographs of the test set-up are shown in Figure 3.



FALSE CEILING

FRONT HALL

REAR HALL

FIGURE 3:
Photos of Structure Chambers and Compartments

The FCD tests in this mock-up TS building involved creating single phase arcing faults at 12 kA and 25 kA inside the bus compartment of the metalclad switchgear housed in the mock-up structure.

5.0 DATA ACQUISITION

Four quantities were recorded during these tests to provide performance comparisons between FCD protected faults and unprotected arcing faults. Since single phase arcing faults were initiated in the metalclad bus compartment, bus compartment pressure rise was monitored. Also, since arcing by-products were vented from the bus compartment into the false ceiling, smoke detector annunciation in the false ceiling was monitored. Third, since arcing faults in the bus compartment can force by-products through the barrier into the breaker compartment, smoke ingress into the breaker compartment was recorded. Finally, since the FCD produces a "bang" when it operates, noise levels in both hallways were recorded.

5.1 Smoke Sampling

Samples of airborne smoke particles were collected with filter packs from the metalclad breaker compartment during each arcing test. Breaker compartment air sampling was carried out with a 47 mm diameter Millipore HAWP 04700 0.46 μm pore size filter that had been previously weighed. The filter was set into an open faced filter holder mounted near the center of the breaker compartment. Polyethylene tubing (9.53 mm OD) was run from the filter pack to a calibrated sampling pump. After each smoke test, the filter was removed and stored in a plastic dish until the final weight could be obtained.

5.2 Pressure Rise Detection

During arcing tests, assessments of pressure rise in the metalclad bus compartment were made using pressure transducers. Similar pressure rise recordings were made in the false ceiling of the mock-up to assess false ceiling response to arcing faults.

5.3 Audible Noise Measurement

Audible noise readings were taken in the structure front and rear hallways. Assessments of peak noise were made and compared to the noise limit of 135 dbA specified in The Ontario Hydro Corporate Safety Rules/4/. Workers exposed to noise in excess of 135 dbA are required to wear hearing protection.

6.0 SMOKE PENETRATION ASSESSMENTS---PARTICULATE DEPOSITION DENSITY

One objective of this test program was to determine whether significant pollution from smoke associated with arcing faults is deposited on unaffected structures during and immediately after a fault. For indoor switchgear, such as the metalclad included in this test program, the bus

itself is often covered to provide additional insulation and to protect it from the environment. Bus support insulators usually contact only the bus covering so that bus insulation compromise from pollution is not likely to be a major potential problem. However, at critical air insulated points, such as the breaker, parts of the current carrying path can be exposed to the local environment, and may therefore be compromised by the deposition of pollution resulting from a fault.

Determining the effect of smoke pollution on exposed, air insulated high voltage components is a difficult task since little research has been done in this area. However, considerable testing has been carried out on the effects of salt on high voltage insulators/5/, and it is possible to develop an analogous parameter to the Salt Deposition Density commonly used to assess insulator pollution. The new parameter, in this case applied specifically to the case of soot deposition on exposed high voltage insulation, has been called the Particulate Deposition Density.

The Particulate Deposition Density (PDD) is the amount of contaminant deposited on a spherical surface surrounding a known volume of air from which smoke is collected.

To determine the electrical significance of PDD values, 60 Hz flashover tests were carried out with 37 glass surfaces (test tubes) polluted with known amounts of carbon soot. Figure 4 presents the relationship between PDD and the reduction in insulation strength of the polluted surface. This relationship may be used as an indicator of the electrical consequences of carbon soot on insulator surfaces.

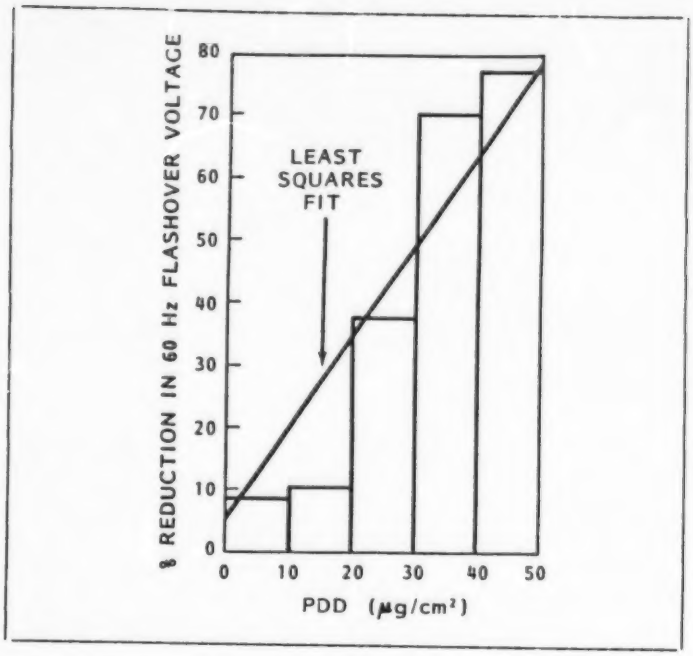


FIGURE 4:
Reduction in 60 Hz Flashover With PDD
(Carbon Soot Pollution)

In figure 4, percent reductions in 60 Hz flashover voltage resulting from carbon soot deposition are presented. An important distinction must be made between the data provided in figure 4 and potential reductions in 60 Hz withstand voltage resulting from carbon soot deposition. Manufacturers design metalclad switchgear to withstand applications of high voltage, for one minute, considerably in excess of rated line to ground voltage. For the case of the 15 kV class switchgear included in this test program, a one minute, 60 Hz withstand level of 36 kV is required by the standards. The reductions in flashover voltage presented in figure 4 do not necessarily indicate corresponding reductions in 60 Hz withstand voltages. To illustrate this point, consider that for a particular piece of equipment for application in this metalclad, it has been demonstrated that the standard requirement of a 60 Hz withstand voltage of 36 kV for one minute has been met. Suppose that design testing has shown that this piece of equipment has support insulators for which 60 Hz flashover is known to occur at 45 kV. Suppose further that a fault has occurred near the equipment and deposited soot to an PDD level of about 9 micrograms/cm^2. Then, from figure 4, flashover reductions of about 18% are probable. This translates to the equipment having a flashover voltage of about 37 kV instead of 45 kV. This means that the performance margins originally

designed into the equipment will have been significantly reduced, even though, in this case, the 60 Hz withstand requirement specified by the standards can still be met.

In other, more extreme cases of soot pollution, reductions in 60 Hz flashover voltages may result in compromises of the rated 60 Hz withstand strength of the equipment; however, without additional detailed design data pertaining specifically to the equipment under assessment, it is not possible, in general, to quantify precisely whether or not particular PDD values would reduce 60 Hz withstand from required levels.

6.0 FAULT CURRENT DIVERTER TESTS

To assess FCD performance, single phase arcing was initiated inside the metalclad bus compartment. Performance assessments were made on the basis of smoke penetration through the metalclad, pressure rise accompanying unprotected and protected faults, and noise levels for protected and unprotected faults.

The following restrictions formed the foundation for the tests:

(i) Since in actual applications, a fault might occur anywhere in the metalclad structure, the diverter was placed at the source end of the test set-up, as shown in figure 5, about 8 metres upstream of the fault in the metalclad.

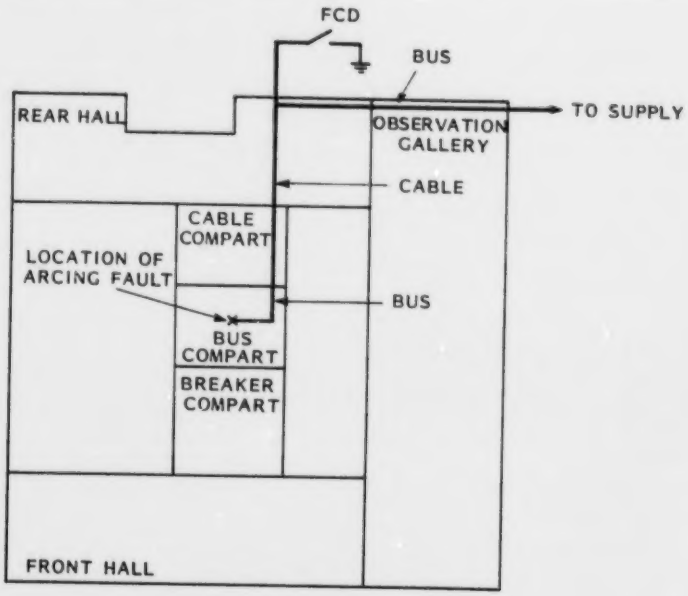


FIGURE 5:
FCD Point of Application During Metalclad Fault Tests

(ii) Only single phase tests were carried out.

(iii) The only available FCD was designed for distribution system application at 12 kA. Accordingly, two series of tests were planned. First, tests at 12 kA were carried out to confirm the FCD performance. Then tests at 25 kA were done to demonstrate the performance improvements at typical fault current levels in this application.

(iv) Fault triggering the FCD in this application was not attempted. The FCD was remotely triggered by laboratory controllers about 3.0 ms after fault arc initiation.

7.1 Test Results---FCD Performance Demonstrated

Figure 6 presents the current oscillograph of one of the tests carried out during this test program. As can be seen, the FCD's fault energy limiting action was initiated in 3.0 ms, and with that, fault current flowing through the fault arc was almost immediately collapsed, thereby rapidly extinguishing the arc.

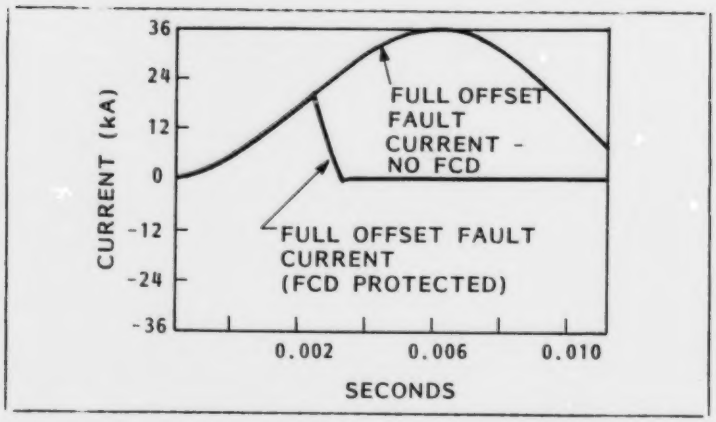


FIGURE 6:
FCD Protected Arcing Fault---Current Trace

Figures 7 and 8 present the pressure rise observed in the bus compartment in response to both FCD protected and unprotected faults at 12 and 25 kA respectively.

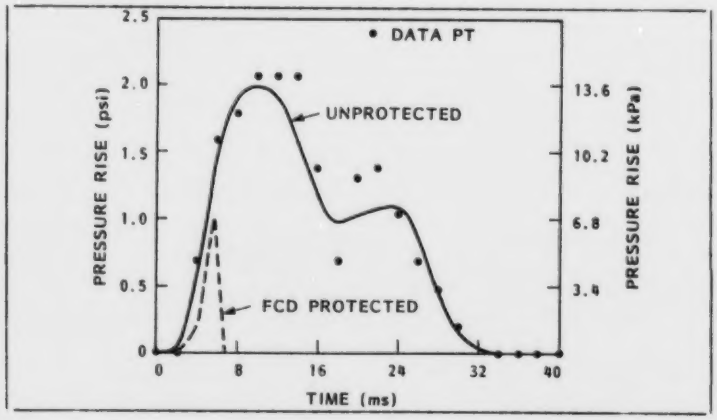


FIGURE 7:
Bus Compartment Pressure Rise with 12 kA Fault.
Unprotected and FCD protected.

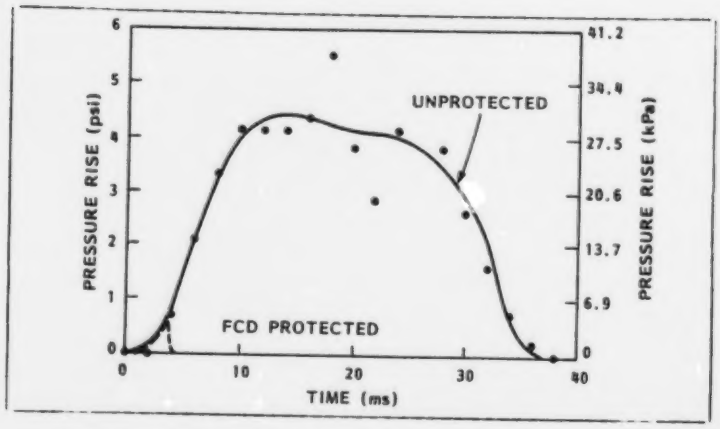


FIGURE 8:
Bus Compartment Pressure Rise with 25 kA Fault.
Unprotected and FCD protected.

In the 12 kA test, unprotected peak pressure reached about 15.2 kPa (2.2 psig) and lasted about 32 ms. In the 25 kA test, peak pressure reached almost 29.7 kPa (4.3 psig) and lasted about 36 ms. In both the 12 and 25 kA tests, FCD operation limited the pressure rise in the bus compartment to 5.5-6.9 kPa (0.8-1.0 psig) or less, with the entire pressure pulse lasting only 5-7 ms.

Table II presents PDD values in the breaker compartment, sound level readings in the hallways, and false ceiling smoke detector response during the tests.

TABLE II: PDD VALUES, SOUND LEVEL READINGS AND SMOKE DETECTOR RESPONSE DURING FCD TESTS

Current (kA)	FCD	Hallway* Sound Level (dbA)	Breaker Compartment PDD ($\mu g/cm^2$)	Annunciation of False Ceiling Smoke Detect?
12	OUT	119	0.50	YES
12	IN	120	0.10	NO
25	OUT	123	2.35	YES
25	IN	118	0.10	NO

* Average reading from front and rear hallways.

Note: Sound level meter readings were obtained at ear height using two instruments, the General Radio 1988 Integrating Sound Level Meter, and the Larson Davis Sound Level Meter. Both instruments were calibrated prior to the tests.

The following observations can be made from the data in Table II:

6.1.1 Significantly less soot was driven into the breaker compartment when the FCD operated than when it did not. The degree of pollution possible in adjacent metalclad compartments can be limited with a properly triggered FCD.

6.1.2 Significantly less smoke reached the false ceiling when the diverter limited arcing. False ceiling smoke detectors did not operate when the bus compartment was protected by the FCD.

6.1.3 Operation of the FCD did not reduce the audible noise levels accompanying an arcing fault in the bus compartment.

7.0 CONCLUSIONS

7.1 The fault current diverter greatly reduces the amount of smoke generated during arcing faults and eliminates problems associated with smoke migration.

7.2 Operation of the fault current diverter eliminates damages resulting from pressure rises accompanying arcing faults.

7.3 Sound levels associated with an arcing fault are not affected by the operation of the fault current diverter.

8.0 SUMMARIZING COMMENTS

It is always less desirable to have to deal with dangerous by-products of a fault than not to have to deal with them. In these tests, the fault current diverter demonstrated that if a way of applying this device could be found, it is feasible to eliminate almost all of the by-products of arcing faults and with that, to greatly reduce the costs associated with repairing arcing fault damages in transmission stations.

Perhaps the greatest potential of the fault current diverter is in applications where improved designs of ventilation systems are difficult to adopt. Retrofit situations represent opportunities for FCD-based fault protection systems because it may be very costly to modify existing TS buildings to incorporate ventilation system enhancements. The diverter is a relatively small, self-standing technology, and since it may require little or no station building modification, FCD-based fault protection systems may be incorporated into existing station designs and may offer many of the same advantages, as far as responding to an arcing fault within its protected circuit, as ventilation system enhancements.

Developing an FCD suited to transmission stations is an achievable goal. Much of the design work resulting in the prototype used during this test program can be transplanted to develop a three phase device. On the

other hand, the difficulty of developing suitable firing criteria cannot be overestimated. FCD operation will take out all portions of the station downstream from the protected point, and therefore, FCD firing criteria must be extremely reliable. It is likely that the development of a practical FCD-based fault protection system suitable for transmission station protection is a long term goal with a 3-5 year horizon.

One possible approach to designing effective fault sensing and FCD firing protocol is illustrated by Neuhoff/6/. Neuhoff suggests using a variety of detectors and transducers (ie. sound, light, noise, etc.) and processing the signals from each transducer to determine whether or not to fire the protection system. Another exciting prospect, as far as FCD application is concerned, is the use of spectrum analysis to detect low level ground faults/7/. This approach also offers promise for finding suitable and reliable FCD firing strategies.

Since FCD performance has been demonstrated to result in significant improvements in the fault performance of metalclad switchgear, it is recommended to further develop the fault current diverter and FCD firing strategies, so that diversion principles will be suitable for TS application.

Approved:

A.F. Baljet
Manager
Research Division

Submitted:

Reinhard Filter
Engineer
Electrical Testing & Development Section
Electrical Research Department

Tom Jarv
Scientist
Environmental Science Section
Chemical Research Department

RF:TJ:TMAC

REFERENCES

1. Filter, R., Jarv, T., "Smoke and Soot Control in Buildings Housing Metalclad Switchgear" OHRD Report #87-309-K, January, 1988.

2. Kee, F.J., "Proposal to Undertake Research into Development of a Fault Current Diverter for Protection of Padmounted Transformers", Oct. 22, 1982.

3. Filter, R., Mintz, J.D., "A New Approach to URD Protection--The Fault Current Diverter" OHRD report #82-68-H, April 28, 1982.

4. The Ontario Hydro Corporate safety Rules---1979, Sect. 331, subsection 1C.

5. Kawai, M., "Insulation for Power frequency Voltage", Transmission Line Reference Book, 345 kV and Above, Chapter 10, pages 296-324.

6. Neuhoff, C.J., "Improving Ground fault Protection by Monitoring Equipment Environment", IAS 79, 41B, pp 1204-1208.

7. Aucoin, M., Russell, B.D., "Detection of Distribution High Impedance Faults Using Burst Noise Signals Near 60 Hz", IEEE Trans. on Power Delivery, Vol. PWRD-2, April 1987, pages 324-348.